National Offshore Wind Research and Development Consortium

Research and Development Roadmap | Initial Release Version 1.0 | October 2018

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Acknowledgements

This initial Roadmap for the National Offshore Wind Research and Development Consortium was produced by the Consortium's internal technical team comprised of offshore wind experts from the New York State Energy Research and Development Authority (NYSERDA), the U.S. Department of Energy (DOE), the Renewables Consulting Group (RCG), the National Renewable Energy Laboratory (NREL), and the Carbon Trust (CT). In addition, the Consortium's various advisory group members and offshore wind developers serving on the Consortium's Board of Directors provided extensive input. The primary authors were Walt Musial (NREL), Richard Bourgeois (NYSERDA), Gary Norton (DOE), Alana Duerr (DOE), Jan Matthiesen (CT), Michael Stevenson (CT), Emilie Reeve (RCG), and Doug Pfeister (RCG).

1 Background

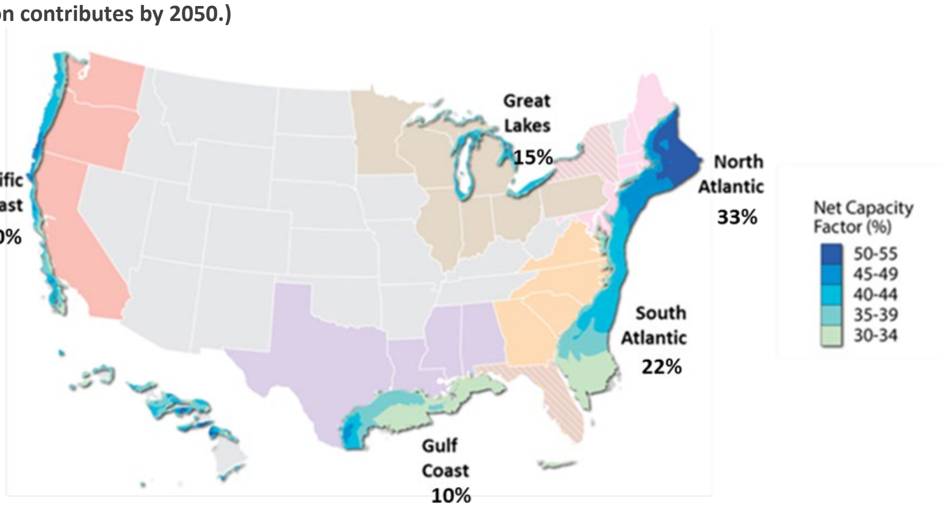
On June 15, 2018 the U.S. Department of Energy (DOE) announced the selection of the New York State Energy Research and Development Authority (NYSERDA), in partnership with The Renewables Consulting Group (RCG) and The Carbon Trust (CT), to lead the formation of a nationwide research and development consortium for the offshore wind industry. The National Offshore Wind Research and Development Consortium ("the Consortium") is a nationally focused, independent, not-for-profit organization led by key offshore wind industry stakeholders and research institutions. The Consortium is dedicated to managing industry-focused research and development of offshore wind to maximize economic benefits for the United States.

The Consortium seeks to fulfill, in part, a long-term vision for offshore wind in the United States that is supported by current U.S. policy for an all-inclusive energy strategy. The 2015 DOE *Wind Vision* report modeled a viable scenario under which 86 gigawatts (GW) of offshore wind energy capacity is installed in the U.S. by 2050, accounting for 7% of all U.S. electricity generation annually through large-scale project deployment in five offshore regions as shown in Figure 1. This vision for offshore wind was elaborated on by Gilman et al. in the 2016 National Offshore Wind Strategy ("the Strategy"), a collaboration between the DOE and the Department of the Interior (DOI).

To achieve this vision, the Strategy identifies technology innovations that will be needed to address the challenges in each of the five U.S. offshore regions and to lower the costs to allow offshore wind to compete in all regional electricity markets without subsidies. The necessary cost reductions can be realized in part through targeted research and development (R&D) funded under this Consortium that removes or reduces technological and supply chain barriers to deployment and lowers development risk to investors. The Consortium envisions this research could be conducted as desktop studies, design development, and computer analysis, as well as hardware development with supporting demonstration and validation activities.

Figure 1. Offshore Wind Regions from Wind Vision

Showing percentages of the 86 GW scenario for each region. (Percentages indicate share of the prescribed 86 GW that each region contributes by 2050.)



The Consortium intends to distribute the available research funds through a series of open enrollment, competitive solicitations over the next four years, which will mirror the three research pillars described in the original DOE funding opportunity announcement (DOE FOA 1767) and summarized as follows:

Pillar #1: Offshore Wind Plant Technology Advancement

Technology advancements that drive significant reductions to offshore wind energy levelized cost of energy (LCOE) in the United States, which can be extended to global offshore wind markets. Accelerated innovation can reduce capital costs and development risk while increasing annual energy production, targeting long-term LCOE reductions for fixed bottom and floating offshore wind systems of 40% and 60%, respectively, relative to baseline LCOE figures presented in the Strategy (2015 U.S. Dollars) (Gilman et al. 2016). R&D conducted under Pillar #1 should also address the domestic physical siting challenges in wind turbine and wind plant technology (e.g., deep water, extreme conditions, fresh water ice, and hurricanes) as well as supply chain issues that may have unique U.S. solutions relative to European experience.

Pillar #2: Offshore Wind Power Resource and Physical Site Characterization

Improvements in offshore wind site characterization and site characterization technology can drive significant cost reduction in U.S. offshore wind projects by increasing annual energy production and reducing wind farm development timelines, capital costs, operations and maintenance (O&M) costs, and project financing risk. R&D under Pillar #2 should address lowering the time, cost, and/or uncertainty of resource assessment and physical site characterization.

Pillar #3: Installation, Operations and Maintenance, and Supply Chain

Installation costs, especially for methods that depend on high-capacity lift vessels and high levels of labor at sea can drive up the cost of floating technology capital expenditures significantly. In addition, the modeled O&M costs for an offshore wind plant in the U.S. range from \$100/kW/year to \$150/kW/year (2015 U.S. dollars), which represents up to 30% of the total LCOE for a fixed bottom offshore wind plant. Finally, the immaturity of the U.S. supply chain may contribute to significant project cost and additional development risk. R&D under Pillar #3 should address technology solutions that will improve installation and O&M methodologies, reduce labor at sea, encourage domestic supply chain development, and subsequently lower cost for offshore wind projects in U.S. waters. While Pillar #3 topics (Section 4) address some specific supply chain R&D areas, supply chain issues are central to the core objectives of the Consortium and consequently are cross cutting in other areas of this roadmap.

This roadmap elaborates on the broad guidance given for these pillars by the FOA to help focus the proposal responses for the first round of competitive solicitations. The solicitations will indicate specific technical topics of interest. It is intended that successful proposals for the first solicitation will be awarded at the end of the first quarter, 2019.

After the first round of competitive solicitations, this roadmap will be regularly revised to incorporate up-to-date stakeholder feedback and adapt to evolving Consortium guidelines. Roadmap revisions are expected to occur periodically (nominally every six months) to incorporate new research priorities and objectives and delete old objectives that have been achieved, while adhering to the Consortium's rules of governance.

This roadmap incorporates input approved by the offshore project developers on the Consortium's Board of Directors who represent the intended end-users of research activities under the Consortium's principles of operation. Input for this Roadmap was solicited by questionnaire and by interviews with board members. In addition, the roadmap relies on expertise from the Consortium's internal technical team comprised of offshore wind expert staff from NYSERDA, DOE, RCG, the CT, and the National Renewable Energy Laboratory (NREL), as well as the Consortium's various advisory groups.

Through the input received and guided by the parameters of the DOE FOA 1767 solicitation, the greatest technical challenges to U.S. offshore wind will be addressed through R&D projects funded by the Consortium.

Please note that all solicitations are expected to adhere to the following general principles:

- Proposers should address issues essential for cost reduction, deployment, and industry expansion specific to offshore regions of the U.S. Proposers of research topics already being addressed globally must explain why further research is necessary.
- Proposal topics will generally adhere to the three research pillars. Additionally, solicitations and project work supported by federal funding must adhere to DOE FOA 1767 guidelines and objectives. In some cases, this roadmap includes important research challenges that may be outside the scope of priorities indicated in DOE FOA 1767. These topics may not be eligible to receive federal funding but may be addressed by the Consortium in the future.
- Proposals should provide benefits to multiple end users. R&D projects that benefit multiple end users are expected to have a greater impact toward achieving the Consortium's industry-wide cost reduction targets compared to R&D projects focused on a developer's specific commercial offshore wind project.

Although the consortium may modify the research objectives in future versions of the roadmap, it is expected the roadmap will continue to maintain an industry-focused, prioritized offshore wind R&D

agenda that enables early U.S. offshore wind project development, LCOE reduction, and geographic industry expansion beyond the currently designated Wind Energy Areas.

2 Pillar #1: Offshore Wind Plant Technology Advancement

2.1 Overview

Pillar 1 research that may be funded includes both fixed-bottom and floating wind technology with a focus on addressing near-term and mid-term challenges for the initial phase of U.S. offshore projects, including technology development that can be achieved by 2030.

2.2 Fixed Bottom Technology

2.2.1 Overview

Fixed-bottom technology is being deployed today using the experience from previous global offshore wind developments, but the conditions on the U.S. Outer Continental Shelf can vary significantly from those in European and Asian sites. The following topics generally reflect U.S. developers' priorities for the initial roadmap:

Cost-reducing Turbine Support Structures for US Markets: Support structure designs in the U.S. may need to deviate from European designs due to different soil conditions, extreme weather conditions, regulatory requirements (e.g., construction noise mitigation), or domestic supply chain availability. Assessment of the suitability of monopiles, jackets, gravity-base, suction buckets, and other types of foundations targeted for U.S. specific conditions are needed. These assessments are encouraged to quantify the following variables:

- Support structure mass and cost scaling
- Domestic installation capabilities
- The development of calculation methods suitable for U.S. soils
- Domestic supply chain opportunities
- Alternative installation methods to mitigate possible environmental impacts and avoid negative cost impacts due to Jones Act restrictions
- Extreme wind and wave resiliency
- Water depth
- Other relevant metrics as determined by the proposer

Enabling the Next Generation of Offshore Wind Turbines: Wind turbines are likely to continue to grow to 15 MW in the next decade, with rotor diameters exceeding 200 m. This will create new challenges in the U.S. for vessel and port infrastructure, large component testing, installation, and maintenance. Adapting current design tools and test methods to enable laboratory validation of large components in existing facilities will be key to de-risk development, improve reliability, understand failure modes, and lower the costs of full-scale component validation tests. Assessments of the system-wide impacts are needed to understand limits to scaling of large machine components and the demands of large machines on the existing infrastructure including manufacturing, installation, testing, and transportation. Included in the topic is the development, improvement, and validation of design and analysis tools to facilitate advancements and optimization of fixed and floating technology. Specific examples may include modeling the dynamic behavior of turbines with ultra-long rotor blades (200 m+) and more flexible coupled systems, which could challenge the development of the coming class of 10 MW and larger wind turbines.

2.2.2 Hurricane Resiliency

Tropical cyclones (hurricanes) commonly occur along the entire Atlantic coast and Gulf of Mexico. In the more northern latitudes, IEC Class 1 turbines are likely to have sufficient design margins to survive these storms, while substructure designs can be adapted using proven concepts and practices from the oil and gas industry (e.g., API RP 2A). As turbines are deployed in regions where hazard curves are steep or extreme winds exceed IEC Class1 criteria, additional mitigation is needed. New strategies are needed to maximize the robustness of fixed-bottom offshore turbine systems (500-year event) by lowering or managing extreme loads due wind and waves, providing additional turbine reserve strength, or adding hurricane ride-through controls and capabilities to extend the geographic range beyond where the current fleet of wind turbines can be safely deployed and remain IEC compliant. Hurricane research activities shall demonstrate extended turbine resilience to withstand higher wind gusts and extreme waves (or odd wind/wave directionality), as well as low-cycle fatigue associated with storm passage, to support the on-going development of structural design standards; for example, design for hurricane conditions to reduce project capital costs and technology risks in current BOEM Wind Energy Areas as well as areas where future projects might be sited (e.g., the Gulf of Mexico).

2.2.3 Array Performance and Control Optimization

As wind turbines and offshore wind project sizes get larger, methods and tools are needed to improve full wind plant (as opposed to individual turbine) annual energy production and increase reliability. For fixed-bottom arrays in the U.S. Wind Energy Areas, new plant-wide optimization methods are needed to:

- Understand differences between wake characteristics in U.S. Atlantic sites and northern European sites
- Understand how U.S. atmospheric conditions may affect wind plant performance and influence turbine loads and reliability
- Improve wind spectra models and verify wake models for optimized plant designs in U.S. waters
- Understand performance and physical behavior of ultra-large rotors (200+ meters) in an array
- Optimize wind plant control to maximize energy capture for varying wind directions and atmospheric conditions found in U.S. Wind Energy Areas
- Estimate system cost in U.S. offshore wind regions using performance and turbine reliability objectives
- Extend wake steering strategies to reduce intra-array turbulence and power losses within existing and future U.S. Wind Energy Areas
- Develop optimization tools for least-cost plant layouts

2.2.4 Power System Design and Innovation

Policy legislation passed in many North Atlantic States is driving the rapid development and deployment of offshore wind. Currently there are more than 10 GW of policy incentives among the states of Massachusetts, Rhode Island, Connecticut, New York, New Jersey, and Maryland, which in aggregate will enable strong market growth; with prices continuing to drop, this type of state policy support is likely to grow. The rapid deployment of offshore wind in the Northeast will create a significant challenge for utilities, developers, regulators, and policy makers who all seek to introduce offshore wind with minimal grid disruptions and at the lowest cost. The default scenario is for each wind project to deliver its power through individual export cable spur lines, which may not be feasible under multi-project build-out scenarios.

Topics that may be considered include:

- New power system technologies/designs/architectures that lower individual project cost, reduce losses, or enable longer distance transmission through the application of new power conversion systems, cable technology, or array power system technology (e.g. MVDC, medium/high voltage switching and interconnection)
- Technology supporting regional or state aggregation strategies that optimize offshore wind power delivery to the grid and enable multiple projects at greater distances to shore
- Technology solutions to reduce cost through the elimination of the offshore substation
- Technology challenges to lower cost and increase U.S. market availability of both turbine-to-turbine array cables and array-to-shore export cables.

2.3 Floating Offshore Wind Technology

2.3.1 Overview

Although almost all commercial offshore wind projects have been deployed in depths less than 50 m and use fixed-bottom substructures and foundations, approximately 58%, or 1200 GW, of the U.S. offshore wind technical resource area is in waters greater than 60 m in depth. The significance of the 60 m depth delineator is that water depths above 60 m are generally recognized as the frontier for nascent floating turbine support structures. As additional near-shore sites in the Atlantic are developed, shallow water areas will become scarcer. Conflicts in siting and landing power from wind plants may necessitate consideration of offshore wind sites greater than 60 m depth, which tend to be farther from shore (Musial et al 2016).

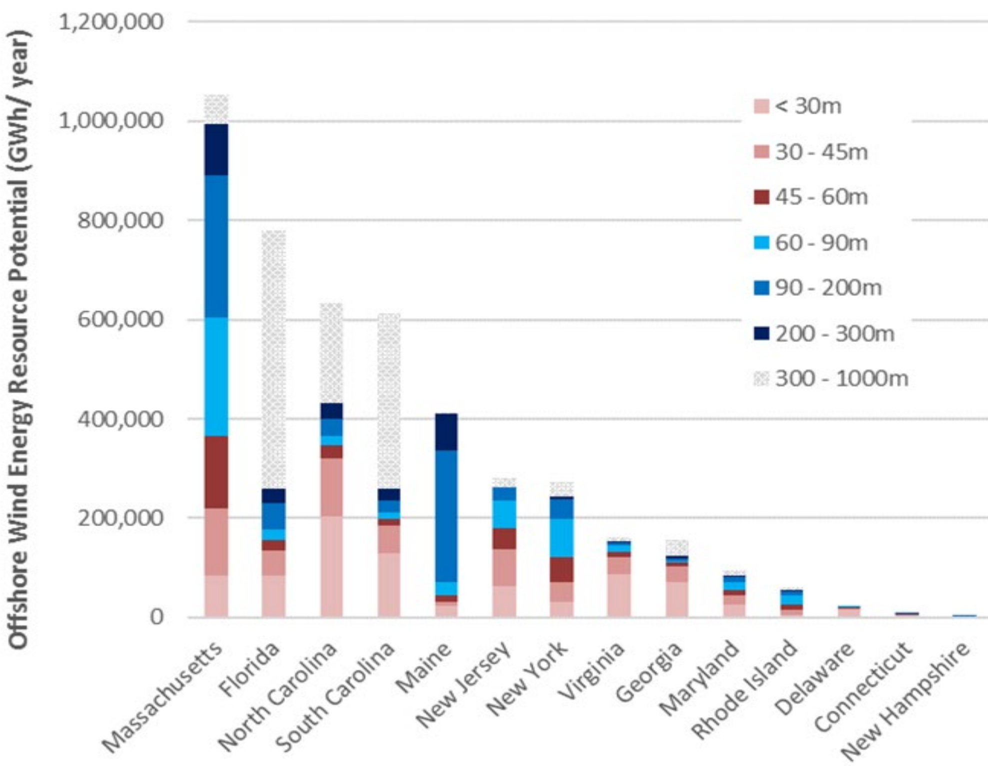
The depth range used to conduct U.S. floating wind energy resource assessments stops at 1000 m, but some experts suggest this outer limit could be extended even deeper. Techno-economic cost models have shown that floating wind technology has the potential to achieve the same cost (or lower) as fixed-bottom offshore wind by 2030 (Beiter et al. 2016, Gilman et al. 2016). As the market expands, learning curve effects and economies of scale can also contribute to lowering floating offshore wind technology cost and achieving parity with fixed-bottom technology (Musial 2018).

The Pacific region, where water depth will likely require all installations to be floating, is expected to contribute 20% (17.2 GW) to the total U.S. offshore wind deployment (Figure 1). However, Pacific offshore wind turbines will likely be in deep waters between 500 m and 1000 m. In the Great Lakes, an additional 700 TWh/year of offshore wind resource over 60 m is present. However, new ice-resistant floating technology is needed to unlock this resource.

In the Atlantic region, as shown in Figure 2, there is an abundance of possible sites at depths between 60 m and 90 m. Just beyond the current lease areas, these sites might be the most accessible for future development but will have significant technology challenges to mooring substructures in shallow water.

Figure 2. Atlantic offshore wind resource energy potential

In Terawatt-hours/year by state showing water depths above and below 60-meters, with 61% of all east coast resource area above 60 m depth.



Technology assessments are needed to reduce the cost of floating technology capital expenditures (CAPEX) to achieve long-term cost targets at or below $60/MWh by 2030. This level of cost reduction cannot be realized by a single innovation. Consortium research should address innovations and improvements that, when combined within a complete system design, can contribute to enough cost reductions to reach this target. The Consortium seeks floating offshore wind research technology proposals that provide the most impact in reducing LCOE.

The following topics reflect floating wind technology priorities for this roadmap.

Shallow Water Mooring Concepts: The U.S. Atlantic coast has a large resource potential for offshore wind at intermediate depths (60-90 m) where floating concepts will be favorable. Current floating offshore wind mooring and anchoring systems (especially catenary mooring types) become more expensive at shallower water depths due to the avoidance of snap loading and anchor uplift forces, more constrained watch circles, and the need to balance stiffer motion frequencies with wave excitation. Large platform motions in storms can cause localized tension spikes (snap loads) in mooring chains because of the large inertia of the chains on the floor. Better technology and design guidelines for shallow water mooring solutions are needed that incorporate more optimized safety factors, new materials and/or alternative design configurations to address shallow water issues, without adding cost, at sites representative of U.S. seabed conditions. New mooring concepts should demonstrate feasibility using dynamic mooring analysis for major IEC design load cases and system cost models and comply with upcoming recommended design, installation and operations practices, and subsequent regulations, for floating systems in U.S. waters. Mooring systems may include catenary spread mooring types as well as tension leg (or taut mooring) platforms suitable for expected soil conditions. Proposed designs for optimized mooring systems may use novel line materials and configurations, potentially including components such as buoys, clump weights, and buoyant towers with emphasis on components and installation methods that utilize U.S. suppliers and installers.

Deepwater Mooring Systems: Greater water depth off the Pacific coast, combined with the need to locate projects far from shore to minimize visual impact, will likely lead to projects in water depth over 500 m. Answering technology challenges in this region will require a deeper understanding of several factors that may constrain deep floating systems. Technology concepts are sought to demonstrate mooring and anchors system designs that assess:

- Practical floating wind depth limits with quantification of the consequences of exceeding arbitrary limits, e.g., the 1000 m maximum depth assumed for the Pacific Coast and Hawaii
- Mooring line spread requirements--how they scale with depth for the California and Hawaii BOEM wind energy call areas, and how they can be optimized
- Mooring line and electric array cable configurations that can minimize impact on fishing activities and other existing use activities
- Potential of new mooring designs to minimize cost and maximize performance for various platform types
- Advanced mooring system designs including methods to automate/expedite anchor and mooring line installation

Floating Platform Scaling: Floating offshore wind platforms have been demonstrated at 6 MW turbine scales, but industry turbines are scaling to 12 MW and beyond. Larger turbines may help lower the cost of large floating offshore wind projects, but not all platforms may scale favorably to larger turbine sizes in terms of substructure size, wave conditions, and compatibility with regional ports and staging facilities. Technology innovation to enable the upscaling and optimization of floating platforms for 12MW+ turbines are needed. Specifically, new innovative platform technology must demonstrate compatibility with the U.S. supply chain, including access to existing assembly ports that can be used or upgraded, use of indigenous materials when possible, and minimal dependence on labor at sea. This research area should build on European efforts such as those conducted by the Carbon Trust (Carbon Trust 2017) and LIFES50+ (Lemmer 2016), which have examined various floating cost and technology challenges.

Control of Large Floating Arrays: Commercial-scale offshore wind arrays are likely to be installed within the next 10 years. Applications for several large floating arrays in excess of 400 MW each have already been submitted to BOEM in Hawaii and California with proposed commercial operations dates around 2025. Currently there is a poor understanding of floating turbine array dynamics and how the turbines will control motions in six degrees of freedom, such as yaw behavior under a waked wind flow. Models are needed to analyze multiple wind and wave scenarios for large arrays with six degrees of freedom, including loading response in various waked conditions to evaluate wake losses; yaw drive duty cycles; turbine/platform pitch dynamics and vertical wake steering capabilities; need for additional actuation; structural loads; and energy capture. This knowledge will lead to more optimized control systems and wind farm control strategies. As appropriate, the research should address advanced controllers that can adapt to site conditions and optimize to multiple objectives. Although these capabilities are needed for U.S. projects, this research could potentially overlap with similar efforts in Europe. Proposers are cautioned to avoid possible duplication with prior or ongoing projects.

Floating Arrays in Fresh Water Ice: The Great Lakes have approximately 700 terawatt-hours per year of offshore wind resource that is over water with depths 60 m or greater. It is likely that to deploy 15 GW of offshore wind in the Great Lakes as modeled under the *Wind Vision* scenario, new ice resistant floating technology will be needed. To develop these concepts, computer tools and substructure and mooring technology must be adapted and bolstered to achieve risk profiles and costs similar to platforms deployed in ice-free regions. New technology solutions should demonstrate local knowledge of statistical lake ice coverage and ice buildup at site locations where floating technology is likely to be deployed.

3 Pillar #2: Offshore Wind Power Resource and Physical Site Characterization

3.1 Overview

Research under Pillar #2 aims to reduce the risk of offshore wind focusing on activities that lower the cost, time, and uncertainty of site characterization for offshore wind developers on the U.S. Outer Continental Shelf. Metocean and physical site characterization activities will focus on data collection and validation, improving site characterization measurement methodologies, validating analytical models used for site characterization.

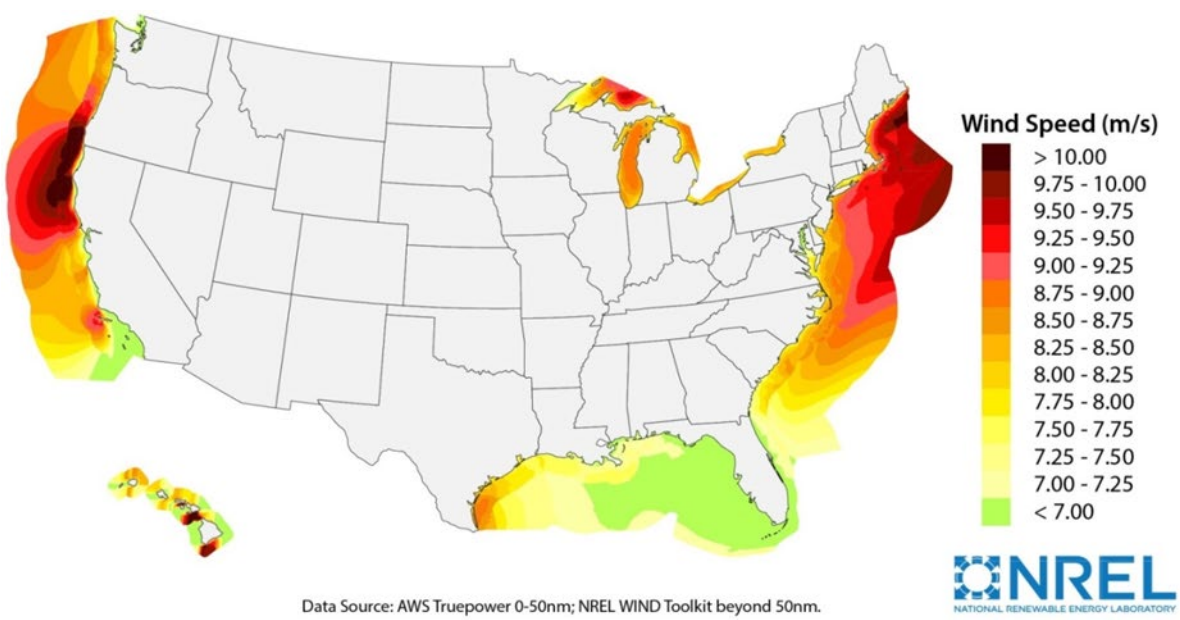
The following topics reflect the Pillar #2 offshore wind power resource and physical site characterization priorities for the initial Consortium roadmap.

3.2 Comprehensive Wind Resource Assessment

The most current national offshore wind resource assessment of the Outer Continental Shelf and Great Lakes was conducted in 2016 by NREL, resulting in the wind speed map shown in Figure 3 (Musial et al. 2016).

Figure 3. Gross offshore wind resource data (100 m)

Used for the 2016 offshore wind resource assessment. Map provided by NREL, AWS Truepower, and Vaisala/3TIER (Musial et al. 2016)



However, there are several data gaps that warrant a more comprehensive analysis. For example, the assessment relies on multiple data sets corresponding to different geographic areas, which in some cases are more than 10 years old and have not been validated with observations. The primary data are based on a typical meteorological year, averaged over 14 years, but there is no temporal component limiting the applicability of the data (e.g., resource adequacy for future grid studies). A detailed database is needed for all offshore wind states on both the East and West Coast as well as the Great Lakes. The database should utilize state-of-the-art meso-scale models and have the benefit of a comprehensive data validation campaign. The validation campaign should also address the uncertainty and variability of long-term wind resource forecasts.

3.3 Systematic Measurement Campaigns

The offshore wind resource on the U.S. Outer Continental Shelf is poorly validated and very few long-term measurements exist near BOEM Wind Energy Areas or at wind turbine hub height. The lack of credible metocean observations drives uncertainty higher for the national resource assessments (described in section 3.2) and in most Wind Energy Areas, which can increase project risk and raise financing costs. Data is needed to reduce the high uncertainty in modeling the resource during operating conditions, including wind-wave-wake interactions. Most available data records were recorded by surface buoys at 5 m height, making hub height estimates subject to significant uncertainty due to variations in atmospheric stability, low-level jets, surface effects, and other measurement errors. Measured data (e.g., floating LiDAR, wave buoys, met masts) at and above hub height are needed for meso-scale model validation and to understand complex metocean phenomena relevant to offshore wind energy production (e.g., hurricane conditions, wind shear, low-level jets, double period swells, atmospheric stability, turbulence). The campaign should include high-frequency measurements to enable validation of turbulence models at BOEM Wind Energy Areas. Data measurement campaigns should demonstrate the ability to deliver interim reports to meet urgent short-term needs but strive for highly credible long-term records.

3.4 Development of a Metocean Reference Site

The development of a Metocean reference site is needed in an open ocean location representative of the near-term BOEM Wind Energy Areas in which innovative methods in wind resource observations and site characterization can be tested and validated. A complementary land-based met mast reference station is also needed where more detailed measurements at higher elevations can be conducted. These met mast reference stations can provide much needed information on turbulence and stability measurement methods and calibration techniques. The reference sites should demonstrate the ability to reduce uncertainty in energy yield assessments for the Wind Energy Areas and assess possible differences/similarities with northern European baseline records (e.g., FINO). Technologies used to perform resource assessments, which may include improved floating and scanning LiDAR systems, large area scanning systems, remote temperature profiling, wave height measurements, SST, etc., need to be verified and validated against standard, vetted observations within a controlled reference test area. Methods for assessing individual methods/sensors, by the industry at large, are needed. Proposed reference sites should seek to build on facilities that may already exist to reduce capital cost and development timelines and comply with FOA 1767 constraints excluding facility development. Although not the main mission of the reference site, long-term monitoring of oceanographic parameters for climate and weather modeling would benefit the industry and may have wider applications for other U.S. businesses that rely on the ocean.

3.5 Sea Bed Survey Methods, Geophysical and Geotechnical Database

Currently the assessment methods available to characterize the seabed soils within the U.S. Wind Energy Areas are insufficient to gather the necessary geophysical design data for efficient conduction of seabed surveys. New methods are needed that can speed up the acquisition of geophysical and geotechnical data for project development, including rapid surface assessment to evaluate the suitability of jack-up vessels in specific locations. In addition, methodologies are needed for the assessment of seabed conditions along array and export cables routes to expedite installation and assess alternative routes.

4 Pillar #3: Installation, Operations and Maintenance, and Supply Chain

4.1 Overview

Research under Pillar #3 aims to reduce the risk of offshore wind by focusing on activities that lower the cost and time of U.S. offshore wind project construction, installation, and operation and maintenance costs through the development of innovative deployment strategies, logistics, machine reliability, advanced maintenance strategies, and critical supply chain elements. Research activities will improve system reliability through the advancement of large component test methods, and the development of strategies to mitigate cost adders due to the Jones Act and reducing dependence on increasingly large heavy lift vessels.

The following topics reflect the initial Pillar #3 offshore wind installation, operations and maintenance, and supply chain priorities.

4.2 Installation

4.2.1 Installation Technology to Reduce Siting Conflicts

Examples of potential siting conflicts during offshore wind construction include collisions of surface vessels with marine mammals, avian species interactions, interference with fishing, and the impact of noise on marine mammals from underwater pile-driving. New technology is needed to reduce risk to wildlife and to increase construction windows, taking into account U.S. regulations and development experience to date. This topic is especially important in areas where endangered species, such as Atlantic right whales, are active. Current techniques to protect wildlife through curtailment of operations may excessively restrict construction windows and increase installation costs significantly. Validated technology solutions that can be integrated into the wind system design at a turbine or farm level shall be considered. Examples of these technologies may include:

- Passive and active subsea acoustic monitoring
- Turbine controls with integrated automated optical systems for avian and bat detection
- Safe deterrent systems to reduce wildlife interactions

4.2.2 Floating Wind Turbine Installation Strategies

The path to commercial maturity of floating wind systems is likely to be challenged by continued turbine capacity growth to 12 MW or greater. To achieve cost-effective floating wind, turbine/platform systems will likely need to be assembled and commissioned at quayside in local or regional port facilities. Developing strategies to execute lower cost installation of floating offshore wind platforms with large turbines is a key technical challenge for project staging at U.S. port facilities. Conceptual methods and installation strategies that consider weights, clearances, platform dimensions, water depth, assembly methods and so on may limit the number of U.S suppliers and sites where these activities can be conducted. Cost trade-off studies are needed to identify viable port locations in the U.S. and the obstacles and barriers that must be overcome.

4.2.3 Heavy Lift Vessel Alternatives

Larger turbines typically require heavy lift vessels with increased capacity. Weight lifting capacity and boom height often determine vessel cost parameters, but the ability to install ever-larger turbines may be limited if the lift capacity of available vessels cannot increase accordingly. Alternative, innovative vessel solutions should be developed, which may be realized through new ship designs or the repurposing of existing U.S.-flagged vessels. Vessel alternatives must be considered alongside turbine/foundation system design to enable cost-effective assembly and installation of 12 MW+ wind turbines in the U.S., in compliance with the Jones Act, and throughout the world.

Other vessels involved in offshore wind construction include cable laying, crew transfer, and service operation vessels. The availability and suitability of these vessels in the U.S. should be studied; technology solutions may be needed to support wind turbine installation, operation, and maintenance using new or existing vessels.

4.3 Operation and Maintenance

4.3.1 Offshore Wind Digitization through Advanced Analytics

A direct method to reduce offshore wind O&M cost is to reduce labor at sea by improving methods of predictive maintenance by combining improved SCADA data analytics, machine learning and condition monitoring technologies. Solutions are sought that can demonstrate increased reliability at component, system, turbine or farm level, or reduce at sea labor hours for O&M personnel on the U.S. fleet of offshore wind turbines. Innovations under this topic may also include advanced sensors, artificial intelligence, and turbine-based robotics to initiate remote repairs, the use of drones and autonomous vessels, and self-healing concepts to reduce manual repairs.

4.3.2 Testing Methods and Infrastructure

The purpose of full-scale drivetrain and blade testing is to increase system reliability and lower field failures by simulating field conditions in a laboratory setting to identify manufacturing and design flaws before field deployment; this helps ensure integrity of the assets for the entire design life. Test apparatus and methods used in U.S.-based test facilities must keep pace with new innovations. Over time, test methods may not adequately represent field operating conditions or may not fully cover the necessary load cases; this is especially true as wind turbines grow in size. As a result, the larger system may be more vulnerable to serial field failures and elevated maintenance leading to higher operational costs. Innovative test methods that can be implemented at U.S. test facilities are needed to:

- Extend current blade and drivetrain testing protocols to larger drivetrain and blade sizes
- Shorten test time to accelerate new system development time
- Increase test accuracy to identify expensive potential field problems in the laboratory

4.3.3 High Sea-State Crew Transfer Solutions

Offshore wind sites in the Pacific Ocean (including California, Hawaii, Oregon, and Washington) have higher average sea states than the Atlantic, North Sea, Great Lakes, or the Gulf of Mexico. As result, the expected availability for operating systems will be lower due to smaller O&M weather windows, which may prevent timely repairs and will likely increase machine downtime. Similarly, construction cost and risk may increase. Cost-effective offshore wind development in these areas may depend on new solutions to widen these construction and O&M weather windows without lowering safety to crew or increasing overall project risk.

4.3.4 O&M Strategies and Tools

Offshore wind facilities are remote and will require further innovations to develop optimum methods for conducting repairs and service under harsh conditions when turbines may not be accessible. The U.S. may have specific requirements due to service port restrictions, weather conditions, and bathymetry that require customized operational strategies. These conditions may vary significantly between fixed-bottom structures and floating structures. Examples may include logistical strategies to optimize vessel availability, crew transport and training, vessel availability, scheduled maintenance, remote monitoring and diagnostics.

4.4 Supply Chain

4.4.1 Technology Solutions to Accelerate U.S. Supply Chain

Many of the components, subcomponents, and infrastructure for the initial phase of commercial offshore wind projects in the U.S. will be imported due to lack of qualified U.S. manufacturing and supply capabilities. Accelerating the maturation of the U.S. supply chain benefits developers, ratepayers, and state governments seeking economic growth and stability, and will bolster the U.S. manufacturing sector. Concepts to stimulate domestic production of offshore wind system components such as substructures, blades, towers, turbine parts and assembly, cables, vessels, and a wide range of subcomponents are needed. Successful concepts should result in increased utilization of existing U.S. manufacturing, new manufacturing, alternative methods of Jones Act compliance, and new system designs that favor local content. Proposed projects are not limited to existing design configurations but may offer collaborative innovations that introduce combinations of new materials, new strategies for deployment, and new advanced manufacturing methods that leapfrog current U.S. market constraints.

4.4.2 Grid Access Study

One of the key uncertainties in building offshore wind in the U.S., and therefore, a major driver for maturing the supply chain, is quantifying suitable access points to interface with the existing onshore grid and understanding the cost of making the interconnections. Since grid access may determine a significant part of a project’s cost, a detailed national study is warranted to identify suitable grid access points, commensurate with the level of offshore wind development anticipated in targeted regions and taking into account power plant retirements and grid expansion requirements.

4.4.3 Detailed Ports and Harbor Study

The development of critical infrastructure, such as ports and harbors, needs to precede offshore development since it may determine project feasibility and cost. Port and harbor development must be planned in conjunction with vessel development to assess the necessary access and project support capabilities. A detailed national research study that characterizes potential ports for collective use by the industry and proposes conceptual plans to advance their development is needed. Such a study would incorporate data and findings of the various national and regional port studies that have been completed in the last decade. Results would include a publicly available “living” database of information on individual ports and the factors determining suitability for the various marine activities related to offshore wind including fabrication, installation, and operations. This analysis would assess strategies to encourage the domestic construction of Jones Act compliant vessels suitable for turbines at the scale anticipated for future development.

4.4.4 Grid Expansion, Reliability, and Upgrades Study

A national-scale study on the long-term integration of 86 GW of offshore wind power capacity into the U.S. electricity system is warranted to assess the needs for building out the existing transmission grid infrastructure in areas where offshore wind is likely to be deployed. The study parameters should follow the 2015 Wind Vision scenario and utilize experience from previous U.S. and EU studies. Sensitivities of key variables including load growth, the future use of energy storage, plant retirements, and penetration of other complementary renewables (e.g., solar PV) should be examined. Although this topic is highly relevant to the successful development of the U.S. offshore wind industry, the topic falls outside the scope of the three research pillars in DOE FOA 1767 and may not be included in the first round of Consortium solicitations.

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